

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
19 July 2001 (19.07.2001)

PCT

(10) International Publication Number
WO 01/51897 A1

(51) International Patent Classification⁷: **G01F 1/712**,
G01P 5/00

Jean-Baptiste [FR/GB]; 13 Polwarth Place, Edinburgh
EH11 1LG (GB). GRAY, Callum [GB/GB]; 12 Viewforth,
Edinburgh EH10 4JF (GB).

(21) International Application Number: PCT/GB01/00089

(22) International Filing Date: 10 January 2001 (10.01.2001)

(74) Agent: NEWBY, Martin, John; J.Y. & G.W. Johnson,
Kingsbourne House, 229-231 High Holborn, London
WC1V 7DP (GB).

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0000484.6 10 January 2000 (10.01.2000) GB

(71) Applicant (for all designated States except US): OPTI-
CAL FLOW SYSTEMS LTD [GB/GB]; Roslin Institute,
Roslin EH25 9PS (GB).

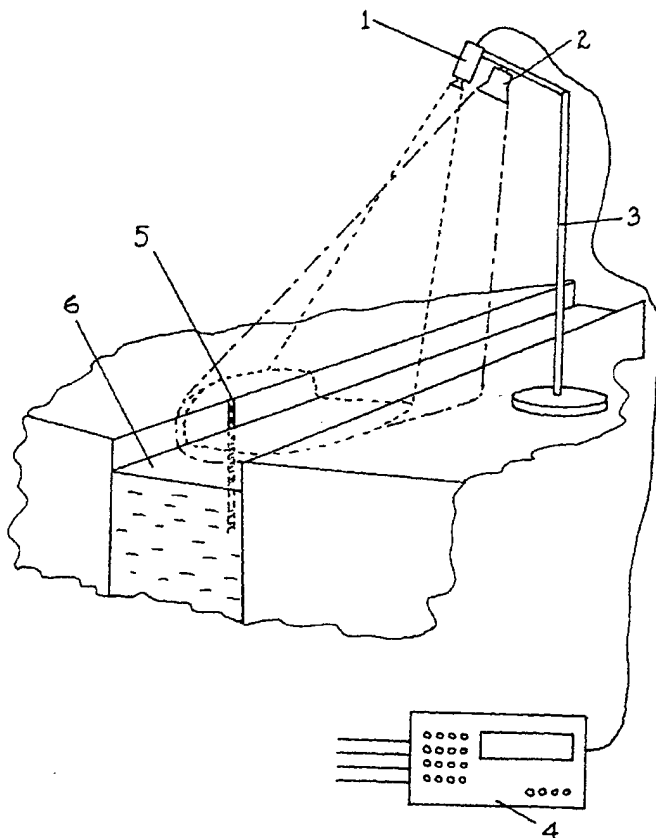
(72) Inventors; and

(75) Inventors/Applicants (for US only): RICHON,

(81) Designated States (national): AE, AG, AL, AM, AT, AT
(utility model), AU, AZ, BA, BB, BG, BR, BY, BZ, CA,
CH, CN, CR, CU, CZ, CZ (utility model), DE, DE (utility
model), DK, DK (utility model), DM, DZ, EE, EE (utility
model), ES, FI, FI (utility model), GB, GD, GE, GH, GM,
HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK,
LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX,
MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK
(utility model), SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ,
VN, YU, ZA, ZW.

[Continued on next page]

(54) Title: MEASUREMENT OF FLOW CHARACTERISTICS OF FLUENT MATERIAL



(57) Abstract: A method of determining the volumetric flow of non-gaseous fluent material flowing over a measuring period along an open channel (6) or along a partially filled closed channel, comprising evaluating images taken at successive intervals of time over the measuring period of the upper surface of the fluent material to provide velocity signals representative of the velocity of the upper surface of the fluent material, providing level signals over the period of time representative of the level of fluent material flowing along the channel, and determining from the level signals and the velocity signals the volumetric flow of the fluent material over the measuring period. The velocity signals are determined by detecting similar surface features or patterns in evaluated images obtained at different times within the measuring period. The invention also covers apparatus for determining the volumetric flow of non-gaseous fluent material along an open or closed channel.

WO 01/51897 A1

BEST AVAILABLE COPY



(84) **Designated States (regional):** ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

- 1 -

Measurement of Flow Characteristics of Fluent Material

This invention relates to a method of determining the volumetric flow of non-gaseous fluent material flowing along an open channel or a partially filled closed channel. In particular, but not exclusively, the invention enables the measurement of the flow rate and/or bulk flow of liquids, such as water, or liquids containing solids, such as sewerage or waste water. The invention also relates to apparatus for determining the volumetric flow of non-gaseous fluent material flowing along an open channel or a partially filled closed channel.

In certain areas of industry, such as the water industry, industries that discharge water-borne waste, and environmental agencies, it is important to be able to measure and/or monitor flow velocities and bulk flow values of fluent materials. In the water industry, in particular, efficient water management requires accurate and reliable measurements to be made of water flows.

Most known liquid flow measuring devices indirectly measure liquid flow rates. Liquid flow measuring devices are commonly classified into those that measure liquid pressure or head and use charts, tables, or equations to compute liquid flow rates from the measured values and those that sense or measure liquid flow velocity.

Examples of liquid measuring devices that measure liquid head, h , or pressure, p , to determine discharge, Q , are: weirs; flumes; orifices; venturi meters; and devices that measure liquid depths using run-up measurements on a flat weir stick. In these cases liquid flow velocity does not need to be directly measured or sensed. The weir equation computes liquid flow velocity from a measuring head such as a weir or flume. Head measuring devices require the construction of the weir or flume which is typically in the form of a fibreglass or concrete channel. Head measurement

- 2 -

requires an additional device such as an ultrasound transducer to detect the variable head value in the flume or weir from which the total liquid discharge is calculated. Weirs and flumes involve civil engineering and with large channels this can involve considerable cost. Also the flow characteristics of these known devices may change if they become fouled and, to prevent this occurring, it is necessary for these devices to require regular cleaning.

Known devices and systems that actually sample or sense liquid flow velocities, v , are: a float and stopwatch; current and propeller meters; vane deflection meters; ultrasonic transit-time velocity measurement devices; and Doppler effect ultrasonic flow meters. These known devices generally do not measure the average liquid flow velocity, V , for an entire flow cross section. Thus, the relationship between sampled liquid flow velocities, v , and the mean liquid flow velocity, V , must be known as well as the liquid flow cross-sectional area, A , to which the mean liquid flow velocity applies. Then, the liquid flow discharge, Q , sometimes called the liquid flow rate, is the product, AV . The accuracy of these known devices is limited by the characteristics of the technique. A float and stopwatch technique is limited in accuracy by the skill of the user. Current and propeller meters are limited by mechanical inertia and by turbulence in the liquid flow as are vane deflection meters. The more sophisticated ultrasonic techniques measure the average liquid flow velocity across a channel from the difference in the transit times of ultrasound pulses moving with and against the flow. These devices require careful setting up and in addition require transceivers to be inserted in the flowing liquid.

Another known type of liquid flow meter is a magnetic flow meter. Magnetic flow meters measure the change in a magnetic field applied around a channel having a liquid flowing through it and use the information to determine the liquid flow discharge through the channel. This type of

- 3 -

flow meter can be used for both closed and open channel flows.

It is also known from US-A-5811688 to measure the velocity of a fluid flowing through a pipe without invading
5 the fluid. This known method of fluid velocity measurement uses the Doppler frequency shift between beams directed at and reflected from the fluid surface.

Other known systems which use imaging techniques to measure the flow rate of fluids are disclosed in US-A-
10 5249238, EP-A-0436125, JP-A-63184070 and EP-A-0505099.

An aim of the present invention is to provide for the non-contact measurement of surface flow velocities of non-gaseous fluent material moving along an open channel or a partially filled closed channel.

15 Another aim of the present invention is to provide an image based measurement system, for measuring flow rates of non-gaseous fluent material, that does not require contact with the flowing fluent material.

According to one aspect of the present invention
20 there is provided a method of determining the volumetric flow of non-gaseous fluent material flowing over a measuring period along an open channel or along a partially filled closed channel, the method comprising evaluating images taken at successive intervals of time over said measuring
25 period of the upper surface of the fluent material as the fluent material flows along a given portion of the channel to provide velocity signals representative of the velocity of the upper surface of the fluent material, providing level signals over said period of time representative of the level
30 of fluent material flowing along said channel, and determining from said level signals and said velocity signals the volumetric flow of the fluent material over said measuring period, each of said velocity signals being determined by detecting similar surface features or patterns

- 4 -

in evaluated images obtained at different times within said measuring period.

Preferably the quality of the velocity signals is evaluated for use in controlling the length of successive intervals of time in which images are taken. Conveniently when a "measurement" is made, surface velocities are first produced and the quality of the velocity data is calculated using a signal-to-noise criterion or the like. If the quality is not sufficiently good, the interval between successive image evaluations is modified, i.e. decreased, using a pre-calculated dependency between surface velocity and the chosen quality criterion, and a new measurement is made. The process is repeated until a sufficiently good signal quality is obtained. This adaptive feature gives the system the ability to optimise measurement accuracy over the complete range of average flow velocities encountered in practice.

The method according to the invention conveniently uses measurements from sequences of video images of the preferably illuminated upper surface of the flowing fluent material. The velocity profile of the illuminated upper surface is conveniently extracted by analysis of consecutive video images, preferably video camera images, using point-wise correlation image processing. A spatial mapping between pixel co-ordinates in the image and positions and displacements in the field of view measured and the known frame rate of the camera allow the measured displacements to be scaled to velocity.

The invention may utilise visible or invisible radiation to form image(s) from which measurements are made. It is particularly preferred to use pulsed electromagnetic radiation, e.g. infra-red radiation. Analysis of the images may involve the use of statistical cross-correlation processing to facilitate the extraction of displacement information from images. Displacements, positions and lengths are scaled to real units using a spatial mapping

- 5 -

that is generated by identification of known positions ("datums") visible within the imaged field of view. Velocity information extracted from the upper surface of the flowing fluent material is enhanced by combination of two or
5 more consecutive measurements.

It is a particular advantage of the present invention that the images of the upper surface of the fluent material are taken by means of imaging means, e.g. a video camera, which is not in contact with the flowing fluent material.
10 In the water industry non-contact with the water is an advantage since it removes the problem of components being fouled by immersion in dirty water. More fundamentally the video camera does not disturb the flow of the fluent material that it is attempting to measure. Additionally,
15 personnel have no contact with the flowing fluent material and maintenance caused by sensor fouling is eliminated. The system has the ability to adapting automatically to changes in the measurement conditions, in particular to changes in the level of the fluent material in the channel, in the
20 magnitude of the average surface velocity and ambient lighting.

Suitably the level of the fluent material flowing along the channel is obtained by use of gauge means, e.g. a measuring gauge or the like, on a side wall of the channel
25 in contact with the flowing fluent material. Preferably the imaging means provides an image of the upper surface of the fluent material against the gauge means, evaluation of these images providing said level signals. The partially immersed measuring gauge should of course remain visible in use even
30 after being immersed for long periods of time in, for example, dirty water. This can be achieved by coating the measuring gauge with commercially available non-stick coatings. In the event of the gauge being fouled it may be cleaned without removal from the channel.

35 For regular channels the depth of the fluent material may be measured by analysing the images of the gauge means

- 6 -

which is positioned within the field of view with the lower portion obscured where it enters the upper surface of the fluent material. The gauge means is typically attached to the wall of the channel and may be arranged such that there
5 is no obstruction to the flow of fluent material.

The directly measured surface velocity and depth of fluent material is combined using standard techniques to give discharge in litres/sec. The channel width, if not known, may also need to be measured.

10 Accurate calculation of the bulk flow requires that not only the velocity at a point be measured but that the velocity profile across the channel be known so that the total discharge can be calculated accurately using the across-channel velocity distribution.

15 The invention provides image and inter-image information used to extract velocity and spatial scale information that may be used to measure flow velocities and bulk discharges.

The method according to the invention has a number of
20 advantages. The primary component of the measurement system for surface velocity measurement has no contact with the flowing fluent material and as such avoids problems of fouling and contamination by the flowing fluent material. This ensures that the imaging means (video camera) does not
25 influence the flow of the fluent material being measured and is not affected in its operation by fouling. As a consequence the need for periodic cleaning or maintenance is eliminated. It is possible to measure the surface velocity of the flowing fluent material and to measure the variation
30 in the surface velocity across the channel. This allows a more accurate and reliable measure of the bulk flow to be obtained compared with known sensors, such as microwave radar, ultrasonic transit time anemometers, that simply measure the average velocity of the flow. This factor is
35 especially important where the flow may be just downstream

- 7 -

of any form of disturbance. Due to the fact that the invention uses images to measure the surface flow the same image data may be used to estimate water depth in regular channels as well as the incidental benefit of providing
5 image information for visual inspection. The invention can be put into effect using components which are both cheap and readily available and the simplicity of the hardware components and robustness of the processing software make the system, apart from occasional replacement of bulbs for
10 the illumination of the upper surface of the fluent material, virtually maintenance free.

According to another aspect of the present invention there is provided apparatus for determining the volumetric flow of non-gaseous fluent material flowing over a measuring
15 period along an open channel or along a partially filled closed channel, the apparatus comprising channel means for providing said channel for the flow therethrough of non-gaseous fluent material, sensing means for providing level and velocity signals representative of the level and surface
20 velocity, respectively, of the fluent material flowing along said channel, said sensing means including imaging means mounted relative to the channel means for providing at successive intervals of time images of the upper surface of fluent material as the fluent material flows along a given
25 portion of the channel, and evaluating means providing said velocity signals by detecting similar surface features or patterns in the images recorded at different times, and means for determining the volumetric flow over said measuring period from said sensed level and velocity
30 signals.

Preferably the apparatus includes illuminating means, e.g. pulsed illuminating means, for illuminating the upper surface of the fluent material flowing along the channel.

Preferably the apparatus includes gauge means in the
35 channel for providing a measure of the depth of fluent material flowing through the channel.

- 8 -

Embodiments of the invention will now be described, by way of example only, and with particular reference to the accompanying drawings, in which:

5 Figure 1 is a schematic perspective view of apparatus according to the invention for measuring at least one flow characteristic of a non-gaseous fluent material flowing along a channel;

10 Figure 2 shows a pair of sample images of the upper surface of fluent material flowing along an open channel of the apparatus of Figure 1;

Figures 3a - 3d illustrates schematically how sampled images are analysed;

15 Figure 4 illustrates schematically one method of determining the depth of fluent material using a measuring gauge;

Figures 5a - 5c show different traces for determining the depth of fluent material in the channel; and

20 Figure 6 is a timing diagram illustrating image exposure and pulsed illumination of the surface of non-gaseous fluent material flowing along an open channel.

Figure 1 shows apparatus for measuring the rate of flow and bulk flow of non-gaseous fluent material, more particularly water in the embodiment described, passing
25 along a channel 6. In Figure 1 the channel 6 is an open channel but it will be appreciated that the channel could be closed provided that it is only partially filled so as to have a distinct upper surface which does not make contact with the upper wall of the channel. The apparatus includes
30 imaging means, e.g. a video camera 1, mounted with illuminating means 2, e.g. a lamp or an array of light emitting diodes, on mounting means 3 above, and on one side

- 9 -

of, the open channel 6. Sequences of images of the upper surface of water, which is illuminated by the illuminating means 2 and flows through the channel 6, are recorded by the video camera 1 and are passed to a processing unit 4. These
5 images include a portion of a measuring gauge or stick 5 (see Figure 4) which is positioned in the channel 6. The stick 5 is partially submerged and provides an indication of the level or depth of the water flowing through the channel 6.

10 The video camera is orientated to view a portion of the channel which is illuminated by the lamp and the measuring stick 5. The camera acquires images of surface features or patterns present on the surface of the moving water. Typical water surface features are bubbles, froth
15 and small solids. The surface features are recorded as a short sequence of images at the frame rate of the camera (typically 25-30 frames per second). The recorded image sequence is forwarded to the processing unit where a sequence of operations is applied to provide width signals,
20 velocity signals and level signals dependent, respectively, on the width of the channel (if not already known), the velocity of the water surface and the depth of water in the channel. These measured parameters are then used, using standard methods, to calculate the bulk flow or surface
25 velocity in the channel. If the quality of the velocity signals is not sufficiently good, the time between successive image measurements can be reduced. In this way the system automatically adapts to the conditions.

The surface features recorded on the image sequence
30 are normally visible on successive images and provide a record of the motion of the water surface in the inter-frame period. Pairs of successive images are analysed together using a statistical cross-correlation operation performed point-wise on a grid across the imaged area to obtain a
35 measure of the surface feature displacement. Displacement values are scaled to real units using an adaptive mapping that is a function of the level of the fluid and which is

- 10 -

generated from four or more datum points in the field of view. The mapping describes the relationship between positions in the channel and position in the acquired images. Actual velocities are calculated by dividing the measured and scaled displacements by the known interframe period. The raw vector data is filtered to remove erroneous vectors. Filtering of erroneous values is achieved by identifying all vectors whose magnitude and/or direction is inconsistent with the known direction of the channel relative to the camera. Because of the random and uncontrolled nature of the surface features from which the measurements are made the above operation is repeated a small number of times and combined by averaging until a complete or nearly complete representation of the surface velocity is obtained. The cross-channel velocity profile is finally calculated by averaging along lines parallel to the sides or "banks" of the channel.

Figure 2 shows an example of two recorded images and Figures 3a - 3d show schematically how these images are analysed. In particular Figure 3a shows raw measured vectors indicating flow direction and magnitude. Figure 3b shows the globally filtered vector field with erroneous vectors removed. The average vector map from several separate measurements is shown in Figure 3c and Figure 3d shows the average channel velocity profile.

The width of the channel is measured from the image at the same time as calibration of the system. Calibration involves the user selecting known points within the field of view seen by the camera. Known points may be marked on the banks of the channel and identified within the images. Once four or more points are identified at one or several different fluid surface levels the system generates the mapping. To estimate the channel width the user then identifies two points adjacent each other on opposite banks of the channel and combined with the mapping this information is then used to calculate the channel width.

- 11 -

The water depth of the channel may be measured in any convenient way, for example using a measuring gauge or a low-power laser. One convenient method of directly measuring the water depth making use of a measuring gauge or
5 stick having a known pattern marked on it is described below with reference to Figure 4. It will be appreciated however that this particular method of depth measurement is only exemplary and that other methods of depth measurement could be used.

10 As can be seen in Figure 4, the known pattern consists of a black strip and a white strip on either side of a black and white banded strip where the dimensions of the banding are known. At calibration time the user identifies the approximate position of the measuring stick
15 in the video image by defining three lines that run the length, or part of the length, of the measuring gauge over the black, white and banded portions of the measuring gauge. The portion of the measuring gauge visible above the water surface is detected using image-processing techniques and
20 the point where the gauge is obscured below the surface is then converted to a water depth measurement.

If a measuring stick or gauge is used as described above to determine water depth, the method of determining the visible portion of the measuring gauge requires the
25 measurement of the variation in the pixel grey levels along the defined lines in the recorded image corresponding to the black, white and banded portions of the measuring gauge. The need for black, white and banded sections on the measuring gauge arises from the varying conditions
30 encountered on the surface of open channels carrying waste water. In many cases the water surface appears dark due to the turbid nature of the waste fluid. In other cases, due to accumulation of foam or scum, the water surface, under illumination, will appear light. The use of both dark and
35 light strips on the measuring gauge ensures that in either of the above cases one transition, either dark strip to light foam or light strip into dark turbid water, will

- 12 -

provide a clearly detectable transition from which the water height can be gauged. However, an ambiguous situation can occur where the surface foam or scum is present on the surface in a patchy fashion. In this situation erroneous
5 measurements may occur where the white strip enters the water surface into light coloured foam while simultaneously the dark strip directly enters the dark water surface. In this case neither the black strip nor the white strip will provide a reliable estimate of the water surface. To deal
10 with this situation the additional striped or chequered strip is included on the measuring gauge where the periodicity of the black and white "chequers" or "bands" is known and constant. Measuring transitions down the length of the chequered strip will show transitions at regular
15 intervals until the strip enters the water surface. In this case whether the water surface is dark or light the regularity of the detected black/white transitions will be interrupted providing an approximate but reliable measure of the position of the water surface. Comparing the rough
20 water surface measurement from the chequered strip with the accurate but potentially ambiguous white/black strip measurements provides information that may be cross-referenced to generate an accurate water depth measurement from most images.

25 The condition that is assessed to determine whether grey level transitions measured from the depth gauge are unambiguous is whether one or both measurements from the plain black or white strips fall sufficiently close to the rough measure achieved from the chequered strip. Additional
30 verification of water depth may be achieved by comparing the present measurement with previous, validated measurements. This is possible since water depth does not change significantly in the time period between measurements (5-30 seconds) and may be used to detect outlier measurements.

35 The method used to determine dark/light or light/dark transitions is based on the detection of sharp and distinct changes in the gradient of the pixel grey levels along the

- 13 -

three strips of the measuring gauge. The grey level gradient is calculated by taking the difference between the first pixel value and the next. If the pixel values are going from dark to light the gradient will produce a positive value and if the pixel values are going from light to dark the gradient will produce a negative value. In the ideal case of the white strip entering a dark water surface there will be a sharp negative going peak 23 (see Figure 5c). In the case of the dark strip entering a light foamy surface there will be a sharp positive peak 21 in the grey level gradient (see Figure 5a). For the banded strip the gradient of the pixel grey levels will produce a series of positive and negative peaks 22 (see Figure 5b) at regular spacing for the section of the measuring gauge that is above the water surface. Regardless of what state the water surface is in the analysis of the banded or chequered strip will result in the regularity of the positive/negative strips being lost and this state is easily detected and used as a reliable rough measure of the water depth as can be seen in Figure 5b.

As mentioned above the processing unit 4 performs a series of processing operations on the video images acquired from the video camera 1. These operations include the analysis of the inter-frame displacement from which surface velocity is calculated, the analysis of the depth measuring gauge and the final combination of these measurements to calculate bulk flow or discharge. Additionally the processing unit incorporates functionality that allows the user to set-up or calibrate the system. The hardware of the processing unit 4 may comprise standard components but must run specific code designed for the purpose of the present invention. The code is designed to perform the analysis described above on video image streams. The software used to implement the set-up and processing of images for bulk flow measurement suitably incorporates a graphical user interface, data management and data logging facilities. Separate operations are implemented as functional nodes on a tree structure allowing sequences of operations to be

- 14 -

linked to each other. The processing sequence is performed repetitively to give periodic samples of the flow field, channel depth and discharge value. These values are stored as a sequence along with date of measurement, time of measurement and various values such as maximum/minimum measured velocity and optionally a measure of measurement quality estimated from the proportion of data filtered from the raw measurements.

A typical flow measurement procedure for measuring the flow of water in a channel will involve the following initial calibration and set-up steps:

1. Select free running image acquisition to position the video camera 1 so that the channel fills the field of view of the video camera.
2. Focus video camera 1 on water surface using an aperture value $> f8$ to ensure good depth of focus.
3. Specify four or more known points in the field of view to generate image-object mapping.
4. Specify position of top-bottom and width of depth measuring gauge.
5. Specify location of opposite banks of channel.
6. Select processing sequence for measurements (this will be a standard sequence).
7. Run optimising facility to determine the optimum acquisition and processing parameters for the channel velocity and density, concentration and homogeneity of surface features.
8. Repeat the calibration process for different levels of water flowing through the channel.

Once the system is initialised and set-up, a typical measuring operation will involve the following sequence of steps:

1. Select start measurement cycle.

- 15 -

2. Loop the system through a data acquisition, data processing and data logging cycle as discussed below.
3. The data acquisition cycle grabs sequence of image pairs and logs them with timing information for processing (Figure 2).
4. The data processing cycle performs first pass analysis of surface displacement using grid-wise cross-correlation (Figure 3a). If signal quality is not good, decrease length of time between successive images in an image pair.
5. Perform filtering according to global characteristics of 1st pass measurements.
6. Perform filtering according to continuity and smoothness of data considerations.
7. Combine filtered output from measurements made from individual image pairs to create average vector-field (Figure 3c).
8. Average vector-values along direction of channel to generate average across-channel velocity profile (Figure 3d).
9. Measure channel depth from the measuring gauge.
10. Compare channel depth measurement with previous measurements to determine if it is consistent or, if a first depth measurement, log the measurement without the consistency check.
11. Combine surface velocity profile, water depth measurement and channel width to generate discharge measurement.
12. Log details of measurement including time, date, discharge, max velocity, min velocity quality factor etc..

The system described above uses spatial mapping, determined by initial on-site calibration, to convert pixel coordinates in the image into positions and displacements in the field of view measured and ultimately into velocity signals. The on-site calibration is implemented for different levels of fluent material in the channel so as to

- 16 -

take account of changes in the level of fluent material that are significant when compared to the distance between the video camera and the upper surface of the fluent material. If these differences in fluid levels were not taken into
5 account there would be fluctuating measurement inaccuracies. By calibrating the system at several different surface levels, it is possible to calculate from the calibration data the dependencies between real world space variables and fluid level. These dependencies are then used to
10 recalculate the spatial mapping every time a measurement is taken, thus ensuring an accurate image-to-real world coordinate transformation.

The sensed level signals, representative of the height of the upper surface of the fluent material in the
15 channel, may be used to control the focusing mechanism of the video camera (or other imaging means) lens to ensure image sharpness irrespective of the distance between the imaging means and the upper surface of the fluent material.

The imaging means is suitably mounted at an angle to
20 the upper surface of the fluent material and is preferably equipped with a polarising filter. The view angle of the imaging means is preferably set at or about the Bragg angle, so that visible reflections of light from the fluid surface are diminished or suppressed and surface features are
25 clearly visible even in conditions of strong ambient lighting.

In another embodiment of the invention, the illuminating means may comprise a source of pulsed electromagnetic radiation, typically infra-red radiation,
30 for illuminating the upper surface of the fluent material. The effective time separation between consecutive illumination pulses is controlled so as to group these pulses into pairs. Figure 6 shows a typical timing diagram with the upper part illustrating image exposure and the
35 lower part illustrating trigger pulses for triggering the illuminating source. The imaging camera typically takes 25-

- 17 -

30 images per second and in Figure 6 exposure of the first image I1 begins at time T1 and end at time T2 with there being a time interval t2 between the end of exposure I1 and the start of the next exposure I2. The period of image capture is t1 representing the time between the start of successive image exposures. The illumination pulses are triggered in pairs P1 and P2, the pulse separation between the pulses P1 and P2 of each pair being t3 and the separation between the first illumination pulse P1 of one pair and the first illumination pulse P1 of the next pair being t4. In the timing diagram the images are shown as pairs of images I1 and I2. t4 is twice as long as t1 (i.e. $t4 = 2.t1$) or the time separation t4 between consecutive pairs of pulses P1,P2 can be considered to be controlled so as to be the same as the separation between consecutive image pairs (e.g. between consecutive images I1). Within a pulse pair, the first pulse P1 is timed to occur while the first image I1 of the corresponding image pair is being exposed, i.e. between time T1 and T2, and typically close to the end of the first exposure. The second pulse P2 is timed to occur while the second image I2 of the corresponding image pair is being exposed, i.e. between time T1 + t1 and T2 + t1, and typically close to the start of the second image exposure I2. The interval t3 between the pulses P1 and P2 of a pulse pair can also be controlled. It will be appreciated that by positioning one pulse P1 of a pair close to the end of one image exposure I1 and positioning the other pulse P2 of the pulse pair close to the beginning of the next image exposure I2, an apparent time interval between two consecutive images is achieved that is much shorter than the interval of time t1 in which the images are actually taken. Provided that the duration of the illumination pulses is short in comparison to the time interval in which the images are taken and there is no negligible interference from other sources of illumination, the apparent time interval between two consecutive images is, as mentioned above, equal to the time interval between two consecutive illumination pulses. This technique is, of course, only achievable by grouping the images in pairs.

- 18 -

When a "measurement" is made, surface velocities are first produced and the quality of the velocity data is calculated using a signal-to-noise criterion or the like. If the quality is not sufficiently good, the interval between successive image evaluations and the interval between successive illumination pulses are modified, i.e. decreased, using a pre-calculated dependency between surface velocity and the chosen quality criterion, and a new measurement is made. The process is repeated until a sufficiently good signal quality is obtained. This adaptive feature gives the system the ability to optimise measurement accuracy over the complete range of average flow velocities encountered in practice.

Although the illuminating means 2 conveniently illuminates the water surface with visible light, it should be appreciated that the illuminating means may "illuminate" the water surface with electromagnetic radiation above or below the visible spectrum. In this case, the video camera would be able to record in the appropriate electromagnetic spectrum.

The invention has been described with reference to water flowing along an open channel. The invention is, however, applicable to the measurement of flow characteristics of other non-gaseous fluent material, e.g. other liquids, liquids containing solids, sludge etc.. The fluent material may also pass along a closed channel or pipe provided that it is not filled and that a camera or the like is able to record surface features of the fluent material as it passes along the channel.

- 19 -

CLAIMS

1. A method of determining the volumetric flow of non-gaseous fluent material flowing over a measuring period along an open channel (6) or along a partially filled closed
5 channel, the method comprising evaluating images taken at successive intervals of time over said measuring period of the upper surface of the fluent material as the fluent material flows along a given portion of the channel (6) to provide velocity signals representative of the velocity of
10 the upper surface of the fluent material, providing level signals over said period of time representative of the level of fluent material flowing along said channel (6), and determining from said level signals and said velocity signals the volumetric flow of the fluent material over said
15 measuring period, each of said velocity signals being determined by detecting similar surface features or patterns in evaluated images obtained at different times within said measuring period.

2. A method according to claim 1, characterised in
20 that the quality of the velocity signals is evaluated for use in controlling the length of successive intervals of time in which images are taken.

3. A method according to claim 1 or 2, characterised in that the upper surface of the fluent
25 material is illuminated with electromagnetic radiation, e.g. infra-red radiation, to facilitate recording of said images at said successive intervals of time over said measuring period.

4. A method according to claim 3, characterised in
30 that the upper surface of the fluent material is illuminated with pulsed electromagnetic radiation at the same intervals of time as said images are taken.

5. A method according to claim 3, characterised in that the upper surface of the fluent material is illuminated

- 20 -

with pulses of electromagnetic radiation, said pulses occurring in pairs with the first pulse of a pair occurring whilst one image is taken and the second pulse of the pair occurring whilst the next image is taken.

5 6. A method according to claim 5, characterised in that the time between the first pulse of one pair of pulses and the first pulse of the next pair of pulses is controlled to be twice the period of image capture.

10 7. A method according to claim 5 or 6, characterised in that the duration of the illumination pulses is short compared with the time of exposure of each image.

15 8. A method according to any one of claims 5 to 7, characterised in that the time between the pulses of each pair is controlled so as to be small compared with the time between the first pulse of one pair of pulses and the first pulse of the next pair of pulses.

20 9. A method according to claim 1 or 2, characterised in that the level of the fluent material as it flows along said given portion of the channel (6) is determined by evaluating images taken at successive intervals of time over said measuring period.

25 10. A method according to claim 9, characterised in that the level of the fluent material flowing along the channel is determined using gauge means (5) on a side wall of the channel (6) in contact with the flowing fluent material.

30 11. A method according to any one of the preceding claims, characterised in that width signals are provided over said measuring period representative of the width of said channel portion, said width signals being used in addition to said level and velocity signals for determining

- 21 -

the volumetric flow of the fluent material over said measuring period.

12. Apparatus for determining the volumetric flow of non-gaseous fluent material flowing over a measuring period
5 along an open channel (6) or along a partially filled closed channel, the apparatus comprising channel means for providing said channel (6) for the flow therethrough of non-gaseous fluent material, sensing means (1,4) for providing level and velocity signals representative of the level and
10 surface velocity, respectively, of the fluent material flowing along said channel, said sensing means including imaging means (1) mounted relative to the channel means for providing at successive intervals of time images of the upper surface of fluent material as the fluent material
15 flows along a given portion of the channel (6), and evaluating means (4) providing said velocity signals by detecting similar surface features or patterns in the images recorded at different times, and means for determining the volumetric flow over said measuring period from said sensed
20 level and velocity signals.

13. Apparatus according to claim 12, characterised in that the apparatus includes illuminating means (2) for illuminating the upper surface of the fluent material flowing along the channel (6) with electromagnetic
25 radiation.

14. Apparatus according to claim 13, characterised in that said illuminating means comprises a source of pulsed electromagnetic radiation, e.g. infra-red radiation.

15. Apparatus according to claim 12, 13 or 14,
30 characterised in that said sensing means includes gauge means (5) in the channel for providing a measure of the depth of fluent material flowing through the channel.

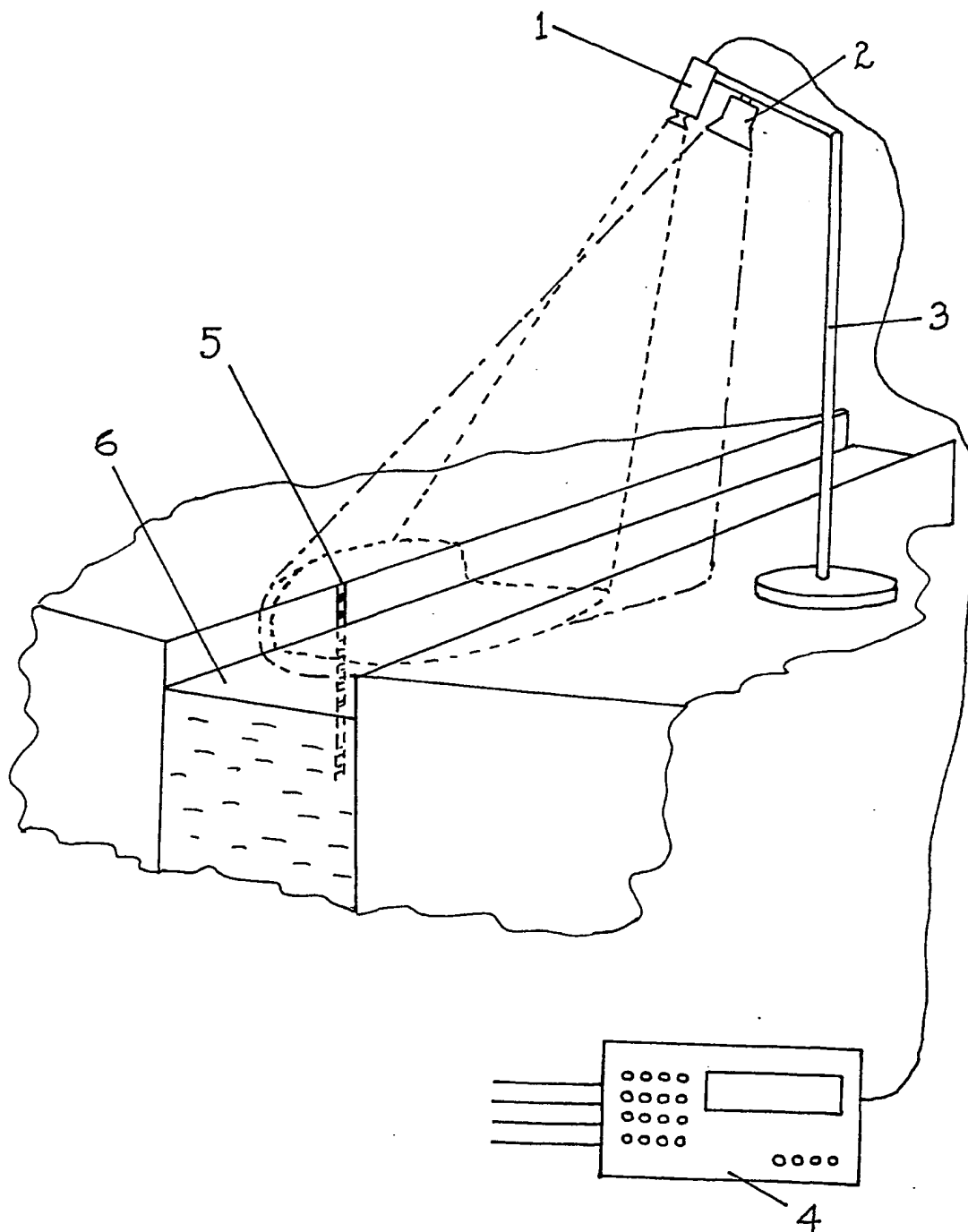
FIGURE 1

FIGURE 2



FIGURE 3

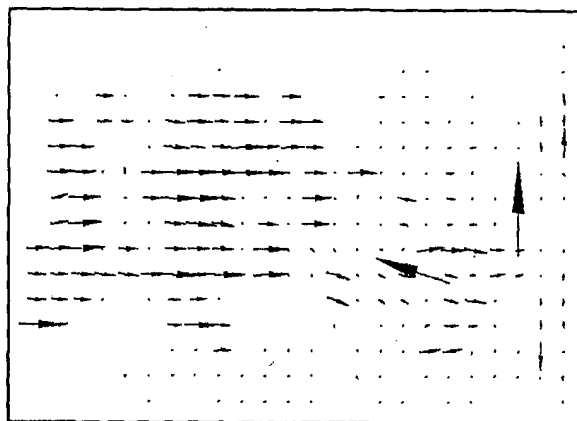


Figure 3a

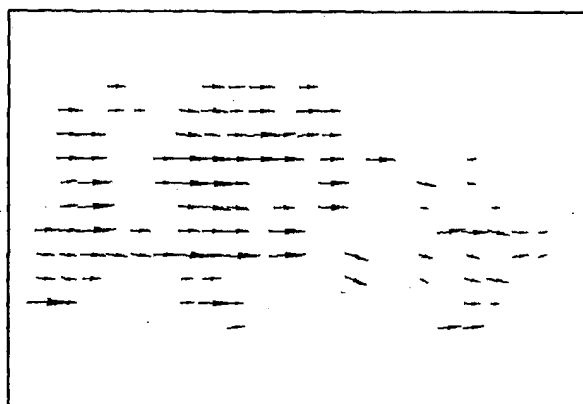


Figure 3b

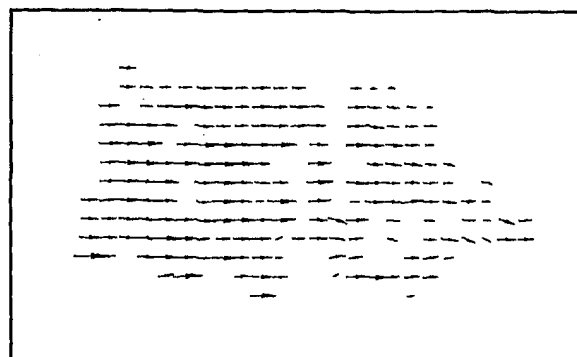


Figure 3c

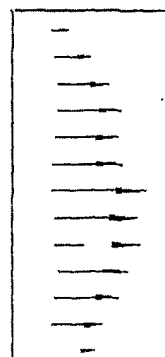


Figure 3d

FIGURE 4

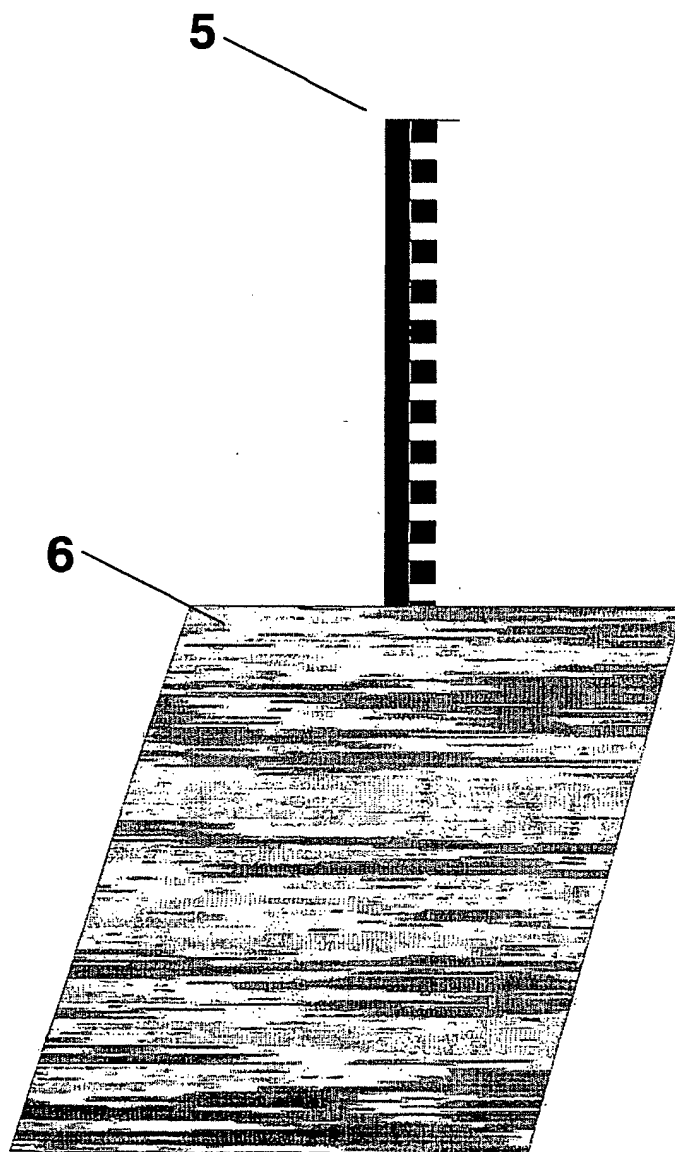


FIGURE 5

Fig. 5a

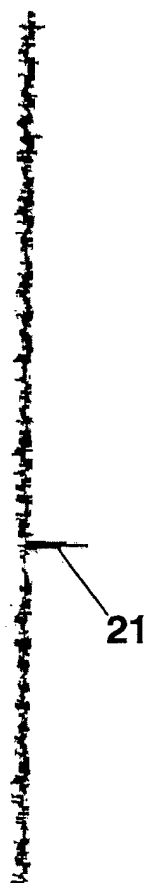


Fig. 5b

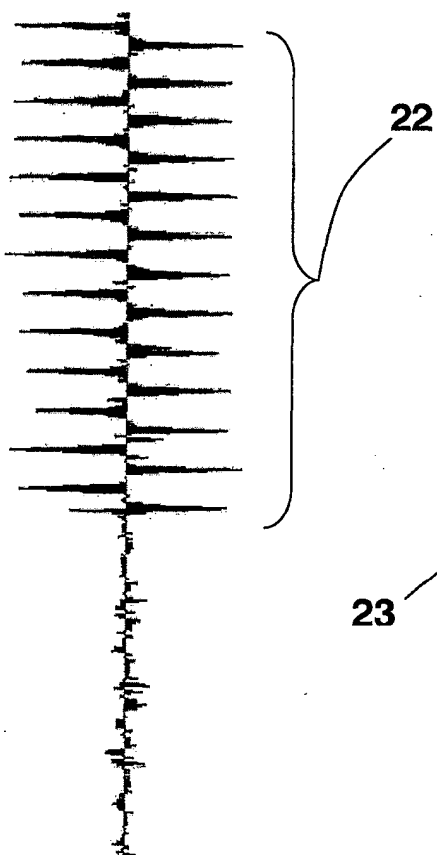
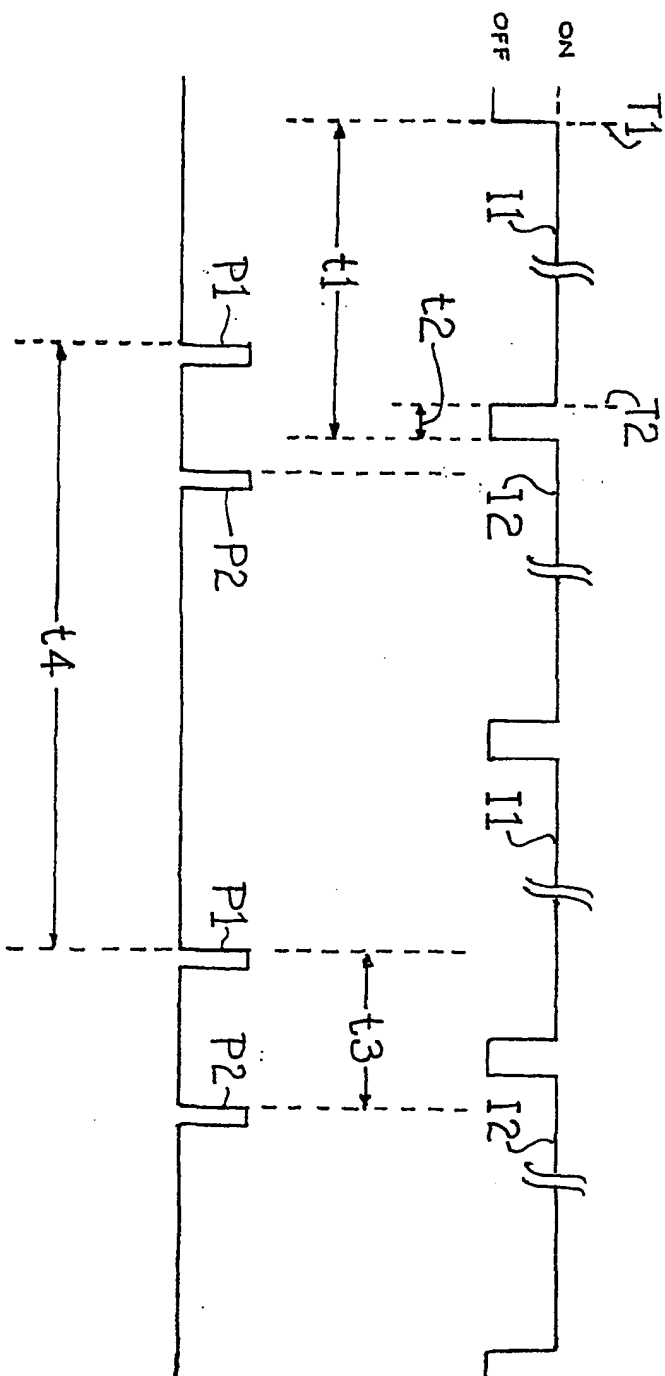


Fig. 5c



FIGURE 6



INTERNATIONAL SEARCH REPORT

Internat Application No
PCT/GB 01/00089

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01F1/712 G01P5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01F G01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 249 238 A (N.M. KOMARATH ET AL) 28 September 1993 (1993-09-28) cited in the application abstract; figures 1-4	1-4, 12-15
Y	US 5 811 688 A (L.M. MARSH ET AL) 22 September 1998 (1998-09-22) cited in the application abstract; figures 2-4	1-4, 12-15

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *G* document member of the same patent family

Date of the actual completion of the international search

6 April 2001

Date of mailing of the international search report

17/04/2001

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Vorropoulos, G

INTERNATIONAL SEARCH REPORT

Information on patent family members

Intern: Application No
PCT/GB 01/00089

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5249238	A	28-09-1993	NONE	
US 5811688	A	22-09-1998	EP 0953827 A	03-11-1999

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☐ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKewed/SLANTED IMAGES**
- ☒ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER:** _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.